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Is Commissioning Once Enough?

Element 5. Integrated Commissioning and Diagnostics
Project 2.2 - Monitoring and Commissioning of Existing Buildings
Task 2.2.5 - Investigate the persistence of the benefits obtained from different types of commissioning and continuous commissionings

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IS COMMISSIONING ONCE ENOUGH?

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ABSTRACT

The Energy Systems Laboratory has developed a commissioning process called Continuous Commissioning[SM] over the last decade. This process is used to resolve operating problems, improve comfort, optimize energy use, and sometimes to recommend retrofits. The process has produced average energy savings of about 20% without significant capital investment in well over 100 large buildings in which it has been implemented. Payback has virtually always been under 3 years with most at two years or less.

This paper describes the process and presents recent evidence of the need for follow-up commissioning when indicated by consumption increases. A case study is presented that specifically shows the value of this follow-up.

INTRODUCTION TO CONTINUOUS COMMISSIONING[SM]

Continuous Commissioning (CC[SM]) started at the Energy Systems Laboratory (ESL) of Texas A&M University as an attempt to achieve energy and cost savings with operations and maintenance (O&M) procedures (Liu et al. 1994). It evolved into a commissioning process that is a way of problem solving in buildings, which helps problems stay fixed longer than conventional trouble-shooting procedures and simultaneously helps reduce energy costs (Liu et al. 1999). It requires knowledge of the fundamentals of humidity, airflow, water flow, and heat flow. This knowledge must be combined with a practical and fundamental knowledge of building systems and building operation to diagnose the cause(s) of problems (Liu et al. 1996). These elements are then combined to solve the problems. Use of this approach typically not only makes problems stay fixed longer; it makes a building operate more efficiently and hence at lower cost. This process attempts to optimize building operation for current requirements. It has primarily been applied to existing buildings, and in that respect resembles what has come to be called retro commissioning. However, it has also been applied to new buildings where it differs from conventional new building commissioning with its emphasis on performance optimization. On-going monitoring of energy consumption with commissioning follow-up as needed has been recommended as an integral part of the process since the mid-1990s.

To date CC has been applied to well over one hundred large buildings with a total floor area of well over 10 million square feet and has reduced energy costs by an average of 20% without appreciable capital investment. Gregerson (1997) investigated existing building commissioning in 1997 and reported average savings of 11.8% for 13 buildings which had undergone conventional commissioning. The average savings noted for the 21 buildings that had undergone CC was 23.8%.

Buildings that have had retrofits and buildings that have not had recent upgrades to the HVAC equipment comprise two significantly different categories to which the CC process has been applied. The average savings due to the process in buildings that had already been retrofit were about 20% beyond the retrofit savings (Claridge et al. 1996). A more recent paper (Claridge et al. 2000) reported that application of the CC process to buildings that had not generally been retrofit produced savings averaging 28% for cooling, 54% for heating, and savings of 2 to 20% for other electrical uses.

THE CONTINUOUS COMMISSIONING PROCESS

The Continuous Commissioning Process is shown schematically in Figure 1 as outlined in Claridge et al (2000).

The first step in the CC process is to perform an initial survey of the building and discover the comfort and operational problems that are present. During this survey,

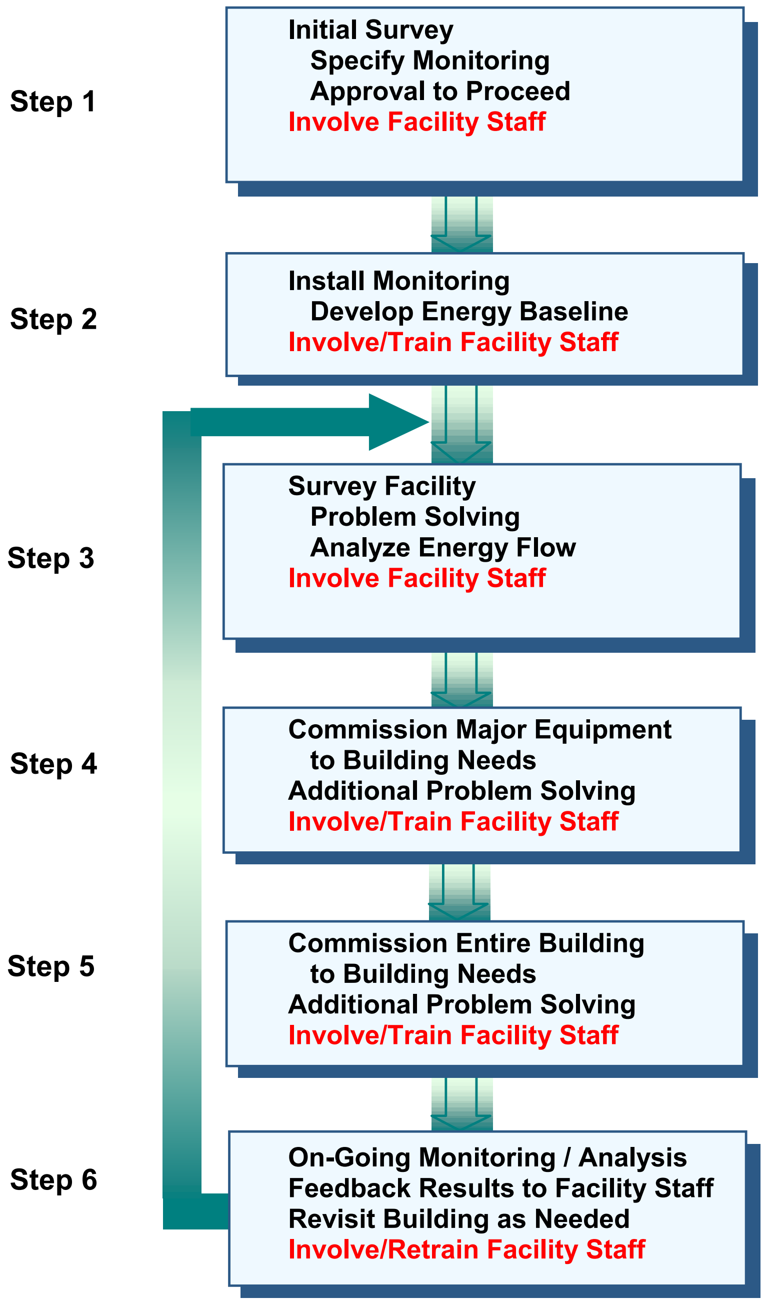

FIGURE 1. THE CONTINUOUS COMMISSIONING PROCESS

an initial estimate of the potential CC savings and an estimate of the monitoring requirements are made. One of the fundamental requirements for CC to be effective is to involve the facility staff in each of the steps so that they will understand and support the planned enhancements to the operations and the facility. Training in Step 1 is usually informal and generally involves discussions as the CC engineer surveys the facility.

A method for measuring and modeling the baseline performance of the facility must be established to determine the impact of the CC process. Equipment is normally installed to separately monitor at least heating, cooling, and other electric consumption on at least an hourly basis and a baseline started in Step 2. This equipment may be installed and owned by the utility or may be owned by the facility. If the metering will be maintained by the building staff, they need to be involved in the installation and should be given installation responsibility if possible. This creates ownership and will allow a much faster repair of sensors when needed. The training in Step 2 is informal and should involve hands-on participation in the installation process.

The CC engineer next performs a detailed facility survey in Step 3. This survey utilizes data from the energy monitoring equipment, the control system, and numerous one-time measurements of temperatures, pressures, and flows made throughout the building. Any broken components or any causes of discomfort are identified and fixed. Also, a team must be formed between the CC engineers and the facility staff. Getting the building back up to proper function is very important as this provides an immediate benefit to the occupants. Having the facility person involved with this step helps to minimize actions by operators to "undo" changes implemented as part of the repair process if complaints occur. Before proceeding, the facility environment should be comfortable and the equipment should be operating acceptably. For example, if the airflow through air handler 5 is increased to improve the temperature in the Dean's Office, discomfort may be created in the EE Department Head's office, two doors down. The CC team identifies these problems, develops a plan for solving them and then solves them. The CC engineers work with the facility staff until solutions are identified and in place. The CC engineer must have an excellent fundamental understanding of the systems in the building combined with substantial practical experience with these systems.

Commissioning the equipment to the facility needs and then commissioning the entire facility to the facility needs are completed in Steps 4 and 5. Commissioning to facility needs involves problem analysis and solution. When equipment is oversized, a typical finding, the operation is usually non-optimal. The CC engineer must understand the operation of the equipment in the equipment room and also how energy is transported in the facility.

Monitoring, in Step 6, is key to measuring the changes and being able to report the savings obtained. Monitoring also serves as an early warning if changes were made in the facility which degrade the operation or savings. A CC engineer needs to visit to facility to review the operation whenever the building consumption increases significantly. Often facility staff change and retraining is important. Also, facility use often changes and these visits will be useful for identifying additional needs at the site. The CC process optimizes the building as it was being operated. For example, if one-half of a floor of offices was converted to labs, it is very likely the energy use of the space will have changed and will need to be optimized. Additional information on the CC process is provided in Liu et al. (1994, 1999) and in Claridge et al. (2000)

CASES WHERE CONTINUOUS COMMISSIONING MAY BE USED

The CC process has been applied almost exclusively to buildings with a floor area of at least 5,000 m^2. About 90% of the buildings to which the process has been applied are in cooling dominated climates where typical cooling consumption in large buildings is at least two times the heating consumption. However, it has also been successfully applied to buildings in the coldest parts of the continental United States. It is a relatively labor intense process at this time, making it generally more applicable to buildings with large air handlers and large total energy use. Automated control systems tend to simplify implementation of CC and it has been particularly effective in buildings that exhibit significant simultaneous heating and cooling. If the CC process were to be implemented in all in the commercial buildings larger than 50,000 ft^2 in the United States, and achieve comparable savings, it would have the potential to reduce consumption in the commercial buildings sector by 8%. Of course, if it were successfully implemented on that scale, it can be anticipated that a variety of automated techniques would make it applicable to smaller buildings and expand the potential impact.

CASE STUDY - KLEBERG BUILDING

The Kleberg Building is a teaching/research facility on the Texas A&M campus consisting of classrooms, offices and laboratories, with a total floor area of approximately 165,030 ft^2. Ninety percent of the building is heated and cooled by two (2) single duct variable air volume (VAV) air handling units (AHU) each having a pre-heat coil, a cooling coil, one supply air fan (100 hp), and a return air fan (25 hp). Two smaller constant volume units handle the teaching/lecture rooms in the building. The campus plant provides chilled water and hot water to the building. The two (2) parallel chilled water pumps (2×20 hp) have variable frequency drive control. There are 120 fan-powered VAV boxes with terminal reheat in 12 laboratory zones and 100 fan-powered VAV boxes with terminal reheat in the offices. There are six (6) exhaust fans (10-20 hp, total 90 hp) for fume hoods and laboratory general exhaust. The air handling units, chilled water pumps and 12 laboratory zones are controlled by a direct digital control (DDC) system. DDC controllers modulate dampers to control exhaust airflow from fume hoods and laboratory general exhaust.

A CC investigation was initiated in the summer of 1996 due to the extremely high level of simultaneous heating and cooling observed in the building (Abbas, 1996). Figures 2 and 3 show daily heating and cooling consumption (expressed in average kBtu/hr) as functions of daily average temperature. The Pre-CC data heating given in Figure 2 shows very little temperature dependence as indicted by the regression line derived from the data. Data values were typically between 5 and 6 MMBtu/hr with occasional lower values. The cooling data (Figure 3) shows more temperature dependence and the regression line indicates that average consumption on a design day would exceed 10 MMBtu/hr. This corresponds to only 198 sq.ft./ ton based on average load.

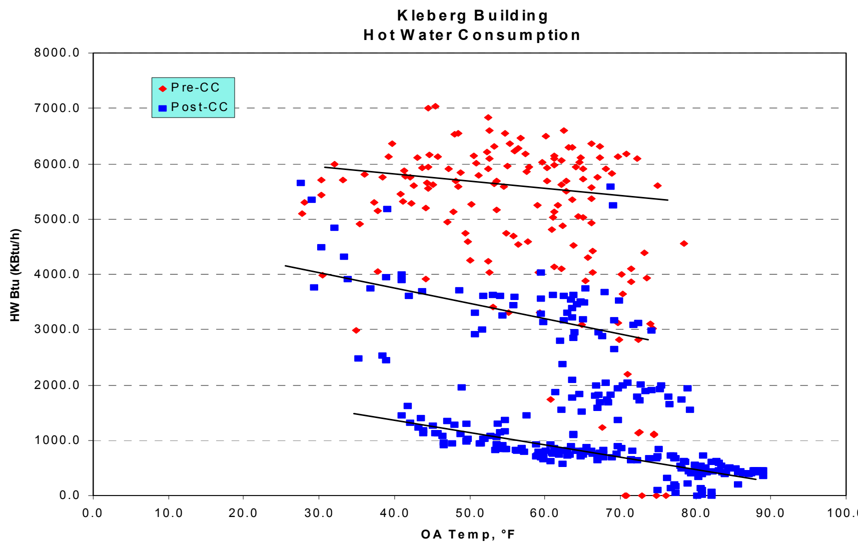

FIGURE 2. PRE-CC AND POST-CC HEATING WATER CONSUMPTION AT THE KLEBERG BUILDING VS DAILY AVERAGE OUTDOOR TEMPERATURE.

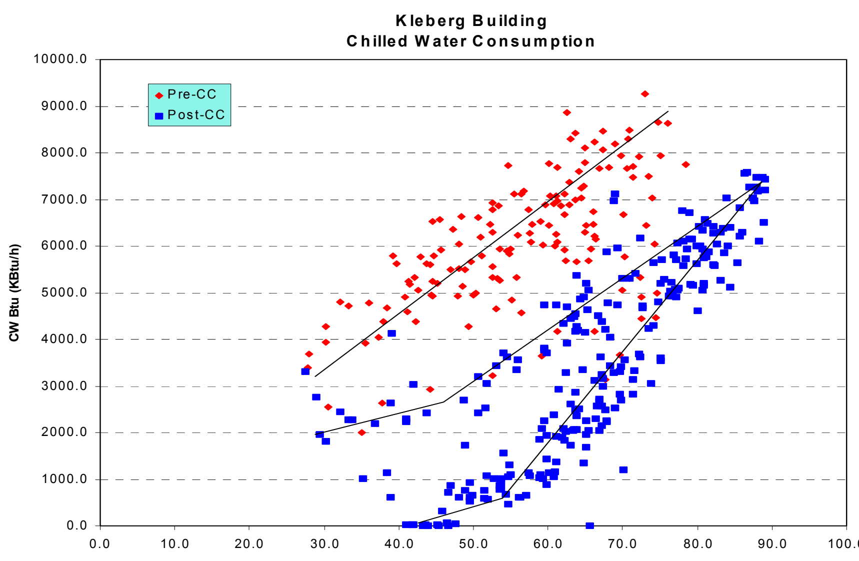

FIGURE 3. PRE-CC AND POST-CC CHILLED WATER CONSUMPTION AT THE KLEBERG BUILDING VS. DAILY AVERAGE OUTDOOR TEMPERATURE.

It was soon found that the preheat was operating continuously, heating the mixed air entering the cooling coil to approximately 105˚F, instituted in response to a humidity problem in the building. The preheat was turned off and heating and cooling consumption both dropped by about 2 MMBtu/hour as shown by the middle clouds of data in Figures 2 and 3. Subsequently, the building was thoroughly examined and a comprehensive list of commissioning measures was developed and implemented. The principal measures implemented that led to reduced heating and cooling consumption were:

- Preheat to 105˚F was changed to preheat to 40˚F
- Cold deck schedule changed from 55˚F fixed to vary from 62˚F to 57˚F as ambient varies from 40˚F to 60˚F
- Economizer – set to maintain mixed air at 57˚F whenever outside air below 60˚F
- Static pressure control – reduced from 1.5 inH2O to 1.0 inH2O and implemented night-time set back to 0.5 inH2O
- Replaced or repaired a number of broken VFD boxes
- Chilled water pump VFDs were turned on.

Additional measures implemented included changes in CHW pump control – changed so one pump modulates to full speed before second pump comes on instead of operating both pumps in parallel at all times, building static pressure was reduced from 0.05 inH2O to 0.02 inH2O, and control changes were made to eliminate hunting in several valves. It was also observed that there was a vibration at a particular frequency in the pump VFDs that influenced the operators to place these VFDs in the manual mode, so it was recommended that the mountings be modified to solve this problem.

These changes further reduced chilled water and heating hot water use as shown in Figures 2 and 3 for a total annualized reduction of 63% in chilled water use and 84% in hot water use. Additional follow-up conducted from June 1998 through April 1999 focused on air balance in the 12 laboratory zones, general exhaust system rescheduling, VAV terminal box calibration, adjusting the actuators and dampers, and calibrating fume hoods and return bypass devices to remote DDC control (Lewis, et al. 1999). These changes reduced electricity consumption by about 7% or 30,000 kWh/mo.

In 2001 it was observed that chilled water savings for 2000 had declined to 38% and hot water savings to 62% as shown in Table 1. Chilled water data for 2001 and the first three months of 2002 are shown in Figure 4. The two lines shown are the regression fits to the chilled water data before CC implementation and after implementation of CC measures in 1996 as shown in Figure 3. It is evident that consumption during 2001 is generally appreciably higher than immediately following implementation of CC measures. The CC group performed field tests and analyses that soon focused on two SDVAV AHU systems, two chilled water pumps, and the Energy Management Control System (EMCS) control algorithms as described in Chen et al. (2002). Several problems were observed as noted below.

TABLE 1. CHILLED WATER AND HEATING WATER USAGE AND SAVING IN THE KLEBERG BUILDING FOR THREE DIFFERENT YEARS NORMALIZED TO 1995 WEATHER.

Type	Pre-CC Baseline (MMBtu/yr)	Post-CC Use/Savings		2000 Use/Savings	
		Use (MMBtu/yr)	Savings (%)	Use (MMBtu/yr)	Savings (%)
CHW	72935	26537	63.6%	45431	37.7%
HW	43296	6841	84.2%	16351	62.2%

Problems Identified

- The majority of the VFDs were running at a constant speed near 100% speed.
- VFD control on two chilled water pumps was again by passed to run at full speed.
- Two chilled water control valves were leaking badly. Combined with a failed electronic to pneumatic switch and the high water pressure noted above, this resulted in discharge air temperatures of 50F and lower and activated preheat continuously.
- A failed pressure sensor and two failed CO2 sensors put all outside air dampers to the full open position.
- The damper actuators were leaking and unable to maintain pressure in some of the VAV boxes. This caused cold air to flow through the boxes even when they were in the heating mode, resulting in simultaneous heating and cooling. Furthermore some of the reheat valves were malfunctioning. This caused the reheat to remain on continuously in some cases.
- Additional problems identified from the field survey included the following: 1) high air resistance from the filters and coils, 2) errors in a temperature

sensor and static pressure sensor, 3) high static pressure set points in AHU1&AHU2.

A combination of equipment failure compounded by control changes that returned several pumps and fans to constant speed operation had the consequence of increasing chilled water use by 18,894 MMBtu and hot water use by 9,510 MMBtu. This amounted to an increase of 71% in chilled water use and more than doubled hot water use from two years earlier

These problems have now been largely corrected and building performance has returned to previously low levels as illustrated by the data for April-June 2002 in Figure 4. This data is all below the lower of the two regression lines and is comparable to the level achieved after additional CC measures were implemented in 1998-99.

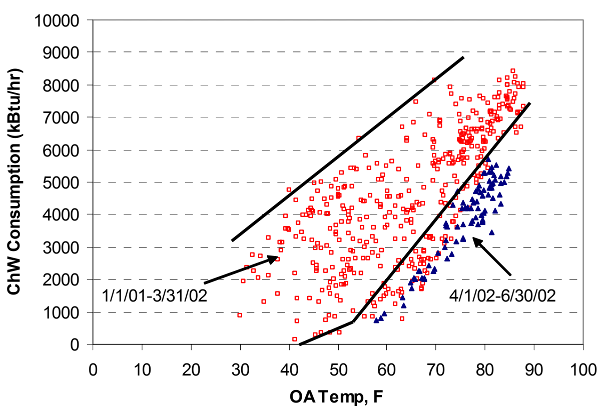

FIGURE 4. CHW DATA FOR THE KLEBERG BUILDING SINCE JANUARY 2001.

WHEN IS FOLLOW-UP COMMISSIONING NEEDED?

For the Kleberg Building, it is clear that a combination of control changes and component problems led to a need for follow-up commissioning measures. In principle, these measures could be viewed as routine maintenance, but since they had not led to comfort problems, it is unlikely that they would have been addressed unless they ultimately resulted in a comfort problem. Even then without the evidence of the $66,500/year increase in consumption, it is unlikely that a comprehensive follow-up effort would have occurred. But how often do such problems occur?

The ESL has conducted a study of 10 buildings on the A&M campus that had CC measures implemented in 1996-97. Table 2 shows the baseline cost of combined heating, cooling and electricity use of each building and the commissioning savings for 1998 and 2000. The baseline consumption and savings for each year were normalized to remove any differences due to weather (see Turner, et al. 2001 for details).

Looking at the totals for the group of 10 buildings, savings decreased by over $207,258 (17%) from 1998 to 2000, but were still very substantial. However, it may also be observed that almost ¾ of this decrease occurred in two buildings, the Kleberg Building, and G. Rollie White Coliseum. The increased consumption of the Kleberg Building was due to a combination of component failures and control problems as already discussed. The increased consumption in G. Rollie White Coliseum was due

TABLE 2. COMMISSIONING SAVINGS IN 1998 AND 2000 FOR 10 BUILDINGS ON THE TEXAS A&M CAMPUS.

Building	Baseline Use ($/yr)	1998 Savings ($/yr)	2000 Savings($/yr)
Kleberg Building	$ 484,899	$ 313,958	$ 247,415
G.R. White Coliseum	$ 229,881	$ 154,973	$ 71,809
Blocker Building	$ 283,407	$ 76,003	$ 56,738
Eller O&M Building	$ 315,404	$ 120,339	$ 89,934
Harrington Tower	$ 145,420	$ 64,498	$ 48,816
Koldus Building	$ 192,019	$ 57,076	$ 61,540
Richardson Petroleum Building	$ 273,687	$ 120,745	$120,666
Veterinary Medical Center Addition	$ 324,624	$ 87,059	$ 92,942
Wehner Business Building	$ 224,481	$ 47,834	$ 68,145
Zachry Engineering Center	$ 436,265	$ 150,400	$127,620
Totals	$ 2,910,087	$ 1,192,884	$ 985,626

to different specific failures and changes, but was qualitatively similar to Kleberg since it resulted from a combination of component failures and control changes. The five buildings that showed consumption increases above 5% from 1998 to 2000 were all found to have different control settings that appear to account for the changed consumption (including the decrease in the Wehner Business Building).

This data does not explicitly answer the question "When is follow-up commissioning needed?", but the authors believe it suggests that tracking consumption and investigating the reasons for significant increases is likely to provide real benefits.

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